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Anticipated Problems of Re-Entry Vehicle Telemetry at UHF

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ANTICIPATED PROBLEMS OF RE-ENTRY VEHICLE TELEMETRY AT UHF

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Summary

Present information on missile range planning indicates that serious UHF telemetry coverage problems are likely to occur during re-entry of ballistic vehicles. Flight test experience at VHF has demonstrated that receiving stations experience difficulty in tracking re-entry vehicles under conditions of rapid changes of signal strength caused by combinations of vehicle motion, vehicle antenna pattern, and plasma attenuation. Similar but greater variations at UHF coupled with narrow beamwidths and reduced sensitivity of re-entry stations portend greater problems at UHF. Conical scan systems may prove inadequate.

Comparisons of similar telemetry systems at VHF and S-band are presented, demonstrating that received signal to noise ratios will be 3 to 9dB below levels presently obtained at VHF for re-entry stations. The narrow antenna beamwidths (1° to 3°) will also cause problems in acquisition so that some form of acquisition aid will be required at each station. Omnidirectional antennas currently used in aircraft at VHF will be useless at UHF. Ships and aircraft will require stabilized or compensated antennas. Acquisition of hypersonic targets will be a particularly severe problem for aircraft receiving stations.

In addition to defining the re-entry problem, system limitations, and expected effects, this paper also makes recommendations to range planners, operators, and users to minimize or correct the anticipated problems.

Definition of the Re-entry Telemetry Problem

Problems involved in re-entry vehicle telemetry are quite different from those of orbiting or booster vehicles. Usually, telemetry from the vehicle is required over the entire trajectory from launch to impact. Since the vehicle orientation with respect to the receiving station changes during flight, the vehicle antenna pattern must radiate some power in all directions so that its directive gain must be low and not far from isotropic level. The antenna is subject to size and material limitations imposed by requirements of survival during re-entry heating and minimum effects on vehicle shape, weight, balance, structural rigidity, and radar cross section. Restrictions of size, weight, and electrical power also limit the transmitter power levels. As a result of the low transmitter power and antenna restrictions, the energy radiated in the direction of the receiver is relatively low especially for small vehicles. This situation is further aggravated at UHF by the many lobes, deep nulls, and changing polarization of typical antenna patterns. The re-entry velocity is high, usually greater than 20,000 ft. per second, requiring high angular tracking rates. During re-entry, plasma attenuation severely attenuates the telemetry signal in addition to the

usual space attenuation. As the vehicle approaches impact, surface reflections cause multipath conditions which increase the difficulty of telemetry reception. As a final requirement, reception of telemetered data is a one-shot affair. Unlike satellite telemetry, there is no succeeding pass to acquire missed data.

Comparison of VHF and S-band Systems

As a preliminary assessment of the effects of changing to UHF telemetry, let us compare the transmission of a typical data bandwidth between a vehicle and receiving station using similar equipment for the VHF band and the S-band portion of the UHF region. This analysis is restricted to a point to point communications problem temporarily ignoring the effects of vehicle motion and plasma attenuation. Vehicle antenna requirements and limitations are similar for both bands so an isotropic antenna pattern will be assumed for each case although the S-band antenna pattern will probably have a greater number of lobes and nulls of various depths. Transmitters are currently available up to 10 watts, completely solid-state, and of similar size weight, and efficiencies in either band. Consequently, for this analysis, the radiated energy is the same for both bands.

The radiated energy is subject to attenuation by space attenuation, plasma loss, and atmospheric absorption. The latter is small in comparison to the other two and can be neglected. Plasma loss is a function of many variables other than frequency including vehicle shape, velocity, materials, air density, temperature, and angle of attack so this complex subject will not be evaluated in this analysis. Since the UHF telemetry band frequencies are approximately a factor of 10 times the VHF, the space attenuation will be close to 20dB greater as calculated from the usual formula:

$$L = 27 + 20 \log f + 20 \log D$$

where L = Space Attenuation in dB
 f = frequency in MHz
 D = slant range distance in miles

For the receiving stations, the best and worst cases of antennas at impact areas will be used. The best case at VHF is the TLM-13, a 60 ft. dish, and the UHF equivalent is the TAA-3, a 30 ft. dish. The worst case for either band is an omnidirectional antenna similar to those currently used in aircraft for receptor at impact.

Since the S-band frequencies are close to ten times the VHF frequencies, the same frequency tolerance of .001 percent produces ten times as much frequency drift and Doppler shift is magnified by a similar ratio. Consequently the receiver

bandwidth must be increased for S-band and a factor of 2 is used as a typical case. Pre-amplifier noise figures are nearly the same at both bands for most stations so a nominal value of 4 dB is used in this analysis.

Using the parameters previously defined, the received signal to noise ratios were computed for the best and worst case antennas as a function of slant range distance. The results are plotted in Figure 1 with indicated thresholds for typical PCM/FM and FM/FM systems. For the best case antennas, the S-band signal to noise ratio is down 6 dB from the VHF level, primarily due to the differences in dish diameters and required receiver bandwidths. Although this reduced performance does not appear to be serious since the signal to

noise ratio is adequate to 5000 miles or more, the large signal strength margin may disappear when plasma attenuation is included. For the worst case, omnidirectional antennas at isotropic gain, it is clear that the omni antenna is unusable at S-band for most applications.

Sensitivity of Ground Station Antenna Systems

For receiving antennas of equal effective aperture area, the increase in space attenuation at higher frequencies is compensated by an equal increase in antenna gain. However, this is not the case for most of the receiving antennas planned or installed for the impact areas of the missile test ranges as shown in Table I.¹

Table I. ANTENNAS AT IMPACT AREAS

<u>STATION</u>	<u>EQUIPMENT</u>	<u>ANT. GAIN</u> (dB)	<u>BEAMWIDTH</u>	<u>PRE-AMP N. F.</u> (dB)
<u>Kwajalein</u>				
VHF	AGAVE	18	20°	4.5
VHF	TELTRAC	19	18°	4.5
S-BAND	TELTRAC	32.5	3°	5
<u>Ascension</u>				
VHF	TLM-18 (60')	28	5°	3
S-BAND	TAA-3 (30')	43	1°	4
<u>WSMR</u>				
VHF	25'	18	15°	4
UHF	25'	39	1.5°	5
<u>Bermuda</u>				
VHF	QUAD HELIX	17	20°	4.5
UHF	TAA-3 (30')	43	1°	4

The sensitivity of a particular antenna is a function of the antenna gain and the pre-amp noise figure since these two parameters determine the received signal to noise ratio at the receiver IF section. In order to compare the expected S-band sensitivity with present VHF sensitivity of a particular station a figure of merit is determined at each band and the resulting figures are compared, taking into account the additional S-band losses of 20dB for space attenuation and 3dB bandwidth losses due to frequency drift and doppler shift.

$$\text{Hence } M_v = G_v - N_v \quad (1)$$

$$M_s = G_s - N_s \quad (2)$$

Where M = figure of merit (dB)

G = antenna gain (dB)

N = noise figure of pre-amp (dB)

And subscripts v and s refer to VHF and S-band respectively,

$$\text{Then } K = M_s - 20 - 3 - M_v \quad (3)$$

Where K = Difference in sensitivity between VHF and S-band.

Evaluating equation (3) for the stations and values listed in Table I yields the following results:

<u>Station</u>	Kwajalein	Ascension	WSMR	Bermuda
<u>Δ sensitivity (K)</u>	-9	-9	-3	+3
<u>Mobile Stations</u>				

Very limited data is available to date for the mobile stations, ships and aircraft. The 2 ARIS and 3 APOLLO ships^{2,4} each have 30 ft. dish antennas with a gain of 35dB. This gain level is considerably below the 43dB gain of the same diameter dish of the TAA-3 land based antenna. The difference is probably due to the relatively inefficient wide-band feed systems employed on the ships. Noise figures of the pre-amplifiers differ for the ships with ARIS having 5.5dB and the APOLLO ship using a parametric amplifier with 2dB. Characteristics of the other range ships are

unknown and will probably vary since conversion to S-band will be made individually.

A similar lack of data prevails for range aircraft. However, the ARIA aircraft of the APOLLO program are operational and are reported to be available for general range use on a non-interference basis with the APOLLO program. These 8 aircraft have nose mounted 7 ft. steerable dishes with 29dB gain at S-band, and pre-amp system noise temperature of 765°K.

Discussion of Problem Areas

Due to the restraints of vehicle equipment, ground equipment, flight dynamics, and propagation effects, data acquisition during re-entry will be considerably more difficult at S-band than VHF. The first problem will be acquisition of the telemetry signal, primarily due to the narrow beam-widths of the receiving antennas. These beamwidths are approximately one-tenth of the VHF figures and will be on the order of 1° at S-band for high gain antennas and 5° for low gain antennas. As a result, an auto-tracking low gain antenna capable of steering the larger antenna or use of some other form of acquisition aid will be required. Acquisition prior to entry into the atmosphere is desirable to avoid the additional problems occurring within the atmosphere but the vehicle antenna pattern and receiving station gain must provide adequate signal strength at the pre-amp input.

If the re-entry vehicle is spinning and/or nutating, as is frequently the case, the vehicle antenna pattern will be turning with respect to the line of sight with possible dropouts due to the many lobes and nulls of S-band patterns. As the vehicle enters the atmosphere, its body motion increases, further aggravating the problem. Finally, plasma attenuation occurs resulting in a greatly reduced signal strength at the receiving antenna. At this time, the lower sensitivity of the receiving stations at UHF could be sufficient to cause data dropouts at signal levels which would have produced good data at VHF. If the signal level drops below the threshold required for auto-tracking, the receiving antenna must continue to track by rate memory or it must re-acquire when the signal strength rises as the plasma attenuation decreases. As indicated previously, re-acquisition will be more difficult than the initial acquisition due to the higher body motion and remaining plasma attenuation. The high body motion in conjunction with a multi-lobed vehicle antenna pattern and changing plasma attenuation will cause rapid fluctuation in the amplitude and polarization of the received signal which the tracking circuits may not be capable of following. Conical scan systems in particular may be confused by changing signal strengths causing false error signals.

As an example of rapid changing signal strength, refer to Figure 2 which is an actual signal strength record of a VHF flight. At approximately 120 kilofeet altitude, the signal strength drops 20dB in 0.45 second due to the sudden increase of plasma attenuation at the time of transition from laminar to turbulent flow surrounding the vehicle. Then between 50 and 25 kilofeet, body motion

and vehicle antenna pattern cause rapid fluctuations of 15dB or so at a 7 Hz rate. Even higher rates have been experienced on other flights and S-band operation would probably produce much greater excursions in amplitude due to pattern lobing. Finally, as the vehicle nears the earth, multipath propagation and polarization shifts will also alter the received signals.

The problems described will be common to all types of receiving stations but ships and aircraft will have others in addition. Shipboard antennas will have to be stabilized or compensated for the ship motion in order to keep the re-entry vehicle within the narrow beamwidth. Also, reflections from other parts of the ship may distort the antenna pattern or sidelobe reception may introduce false error signals. The aircraft problems will be even more severe. As shown in Figure 1, an omnidirectional antenna will be completely ineffective at S-band. The gain of the antennas employed will be limited by physical size and by the necessity for a steerable antenna. Aircraft motion is much worse than ship motion so that some form of stabilization will be mandatory. Initial acquisition will be more difficult than for other stations since the aircraft location is constantly changing. The antenna pattern will probably be distorted by the aircraft structure and may change as the antenna is steered. Due to the relatively low gain of the aircraft antenna, telemetry loss is virtually certain during plasma attenuation. Since aircraft are frequently the only means of obtaining telemetry data immediately prior to impact, rapid re-acquisition will be required in spite of its many problems.

Due to the problems described, manual tracking at any type of station will be completely impractical except in a few special cases where trajectories are consistent and well known before flight. Detailed examinations of telemetry coverage at VHF during the past three years have shown numerous instances of data loss due to stations losing track when rapid signal strength fluctuations occurred or failure to re-acquire after blackout. Unless adequate precautions are taken, this situation will be more prevalent at S-band.

Recommendations

The following recommendations are suggested as possible solutions to overcome the anticipated problems of re-entry telemetry at S-band:

1. Vehicle antenna design. Design efforts should be increased to develop antennas of desired angular coverage with minimal lobing. Scaling of past VHF antennas will not be adequate. The antennas may be required to operate at higher power levels than required at VHF.
2. Transmitters. Since the sensitivity of receiving stations is generally less at S-band than VHF, transmitter power should be increased to provide adequate signal margin. Since this increases battery power requirements and weight, dual power transmitters are suggested to minimize the power required. The transmitter would be switched from low power to high power (perhaps 10dB greater) shortly before re-entry.

3. Station sensitivity. The relatively poor sensitivity of some stations should be increased by installation of higher gain antennas and/or low noise pre-amplifiers, including the possible use of cooled amplifiers to reduce thermal noise.
4. Receivers. Fast AGC systems capable of wide dynamic ranges should be used in both data and tracking receivers to follow the expected signal fluctuations.
5. Diversity reception. Polarization diversity receiving systems are desirable to reduce multipath and polarization shift problems. At present, planning indicates either left hand or right hand circular polarization of receiving antennas for most stations but only a few can receive both simultaneously. Simultaneous LH and RH to two receivers is better but still undesirable since it will require expensive patching of data. If polarization diversity reception were assured, vehicle antenna design would be much less complex.
6. Auto tracking systems. Monopulse tracking is recommended rather than conical scan which might become confused by signal strength fluctuations at multiples or sub-multiples of the conical scan rates.
7. Antenna Stabilization. For mobile stations such as ships and aircraft, some form of stabilization or compensation will be needed. A stable inertial platform would probably be the best reference although costly. Aircraft receiving antennas should be both auto tracking and stabilized to facilitate acquisition of the telemetry signal.
8. Acquisition aids. Due to the narrow beamwidth of S-band antennas, some form of acquisition aid will be mandatory, particularly for stations in re-entry areas. The acquisition problem will be especially difficult for aircraft. Among the possible techniques of acquisition aids are radar beacons on the re-entry vehicle, optical beacons or flares, antenna pointing by computer generated data, programmed auto-scan patterns, and auxiliary low gain, wide beamwidth antenna systems. The C-band radar beacon is commonly employed at present in sites where the C-band radar is located near the telemetry station. This has been particularly effective on ships such as ARIS and the Range Tracker. The following quotation is displayed at ARIS headquarters, Patrick Air Force Base, Florida:

"Blessed are those whose re-entry vehicles bear beacons, for they shall be delivered much ARIS data".

However, use of the C-band beacon is limited by the small number of stations having C-band radars close to the telemetry antennas and by the fact that some

vehicles cannot have their heat shields disturbed by the necessary beacon antennas. At present, no aircraft are equipped with this type of radar installation.

Optical aids, such as laser trackers or autotracking radiometers are not sufficiently developed at this time. Antenna pointing by commands from a computer or relayed coordinates is a promising method successfully employed at present at WSMR. However, it requires a real time computer and good communication links between stations. This would be a problem at remote stations such as Ascension or Kwajalein but it might be feasible by use of relay satellites for the necessary communication links. This method might also be usable for aircraft providing that the aircraft antenna is stabilized and the aircraft position is known to sufficient accuracy.

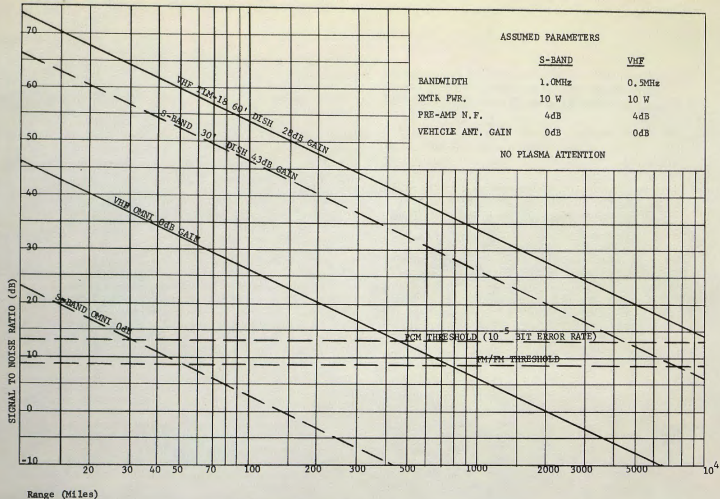
The auto scan pattern about a programmed axis seems to be the second best choice for aircraft if the necessary communication and position requirements cannot be met. Where a low gain antenna is used as an acquisition aid to the high gain antenna, it too will require some form of preliminary direction and self tracking capability.

9. Data Exchange. Considerable improvement is needed in the exchange of information between range planners, operators, and users, particularly with regard to existing equipment and future planning. To remedy this situation, a Range Conference is recommended at semi-annual intervals where representatives of planners and operators of each range, system management contractors, and range users shall meet to present recommendations and to participate in informal discussions.
10. Test flights. Because of all the anticipated problems outlined in this paper, the probability of success for initial S-band flights is not very good. Therefore, we should not develop our learning curve at the expense of costly mission failures but instead should use piggy-back experiments or low cost flights to determine the UHF capability of the receiving stations as soon as possible.

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Range (Miles)

Figure 1 - Received Signal Comparison of Similar Systems at VHF and S-Band

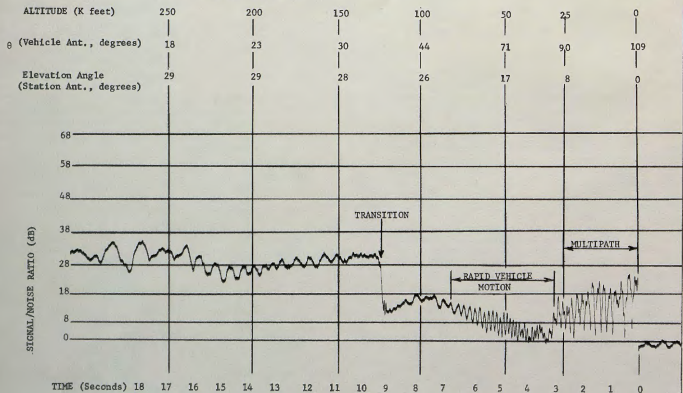


FIGURE 2 - VHF Signal Strength during re-entry.